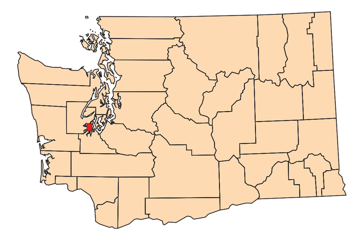
WASHINGTON STATE DEPARTMENT OF
Natural Resources
Doug Sutherland - Commissioner of Public Lands
Division of Geology and Earth Resources
Ron Teissere - State Geologist

Lambert conformal conic projection
North American Datum of 1927. To place on North American Datum of 1983 move the projection lines 23 meters north and 95 meters east as shown by dashed corner ticks.
Base map from scanned and rectified U.S. Geological Survey 7.5-minute Squaxin Island quadrangle, 1959, revised 1994.
Digital cartography by Charles G. Caruthers, Anne C. Heinitz, and J. Eric Schuster.
Editing and production by Karen D. Meyers and Jaretta M. Roloff.

SCALE 1:24 000

1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER

contour interval 20 feet



Geologic Map of the Squaxin Island 7.5-minute Quadrangle, Mason and Thurston Counties, Washington

by Robert L. Logan, Michael Polenz, Timothy J. Walsh, and Henry W. Schasse

2003

INTRODUCTION

The Squaxin Island quadrangle is located at the south end of Puget Sound and covers a complex of inlets and passages that weave between Squaxin Island and mainland peninsulas. The quadrangle is rural residential and agricultural land.

GEOLOGIC HISTORY

Late Wisconsinan–age Vashon Drift covers most of the quadrangle. Pre-Vashon units are generally exposed only along coastal or river bluffs, where mass wasting is common. Landslides and colluvium disrupt and obscure the continuity of exposures so that pre-Vashon geologic history is not easily deciphered. In the Puget Lowland south of Tacoma, all finite radiocarbon ages reported before 1966 are suspect due to laboratory contamination (Fairhall and others, 1966, p. 501). Stratigraphic assignments based on these radiocarbon ages are now questionable and need to be re-evaluated. We have systematically sampled all datable material from nonglacial sediments subjacent to the Vashon Drift and found them to be older than previously reported. With a few exceptions, these sediments have been beyond the range of radiocarbon dating.

The antiquity of the pre-Vashon units causes radiocarbon dating to be of little help for making correlations, and abrupt facies changes within glacial and nonglacial units also render correlations tenuous. Despite these difficulties, we have developed a conceptual model for the more recent pre-Vashon geologic history that is consistent with our observations but by no means compelling.

The oxygen-isotope stage 6 glaciation, called the Double Bluff Glaciation in northern Puget Sound, was probably as extensive as the stage 2 or Vashon Stade of the Fraser Glaciation (Mix, 1987; Fig. 1). The end moraines of this glaciation lie a short distance beyond the inferred limit of the Vashon ice in the vicinity of Tenino, south of this quadrangle (Lea, 1984). Subglacial erosion was probably similar to the erosion that Booth (1994) documented beneath Vashon ice and would have left accommodation space for deposition during the interglacial time of oxygen-isotope stage 5.

The oxygen-isotope stage 4 glaciation, called the Possession Glaciation in northern Puget Sound, was mild relative to stages 2 and 6 (Mix, 1987, and Fig. 1), represented by the Vashon and Double Bluff Drifts respectively in the Puget Lowland. The Possession ice sheet probably did not extend far south of Seattle (Lea, 1984; Troost, 1999). Because the ice sheet blocked drainage out of Puget Sound to the Strait of Juan de Fuca, a proglacial lake was impounded covering most of the southern Puget Lowland. Streams flowing into this lake, such as the Nisqually, Puyallup, and Skokomish Rivers, formed an alluvial plain and deltas grading to lake level. These nonglacial sediments, deposited during stage 4, are all radiocarbon-infinite and overlie and interfinger with Possession glacial outwash deposits. Once Possession ice no longer impounded the lake (but sea level was still significantly below modern sea level), existing drainages, such as the Skokomish, Nisqually, and Puyallup Rivers, deeply and rapidly incised into their former alluvial plains and became entrenched. At least initially, stage 3, called the Olympia nonglacial interval locally (Armstrong and others, 1965), was characterized by downcutting and erosion. As sea level began to rise, most deposition was confined to these entrenched channels. Because stage 3 sea level was probably about 100 feet lower than modern sea level (Ludwig and others, 1996, and references therein), stage 3 deposits were areally restricted. As Vashon ice advanced and sea level fell again at the beginning of stage 2, these rivers preferentially downcut in the same channels, thereby eroding most of the late Olympia deposits, so that finite-aged Olympia deposits are rare above sea level. For pre-Vashon nonglacial deposits that are radiocarbon-infinite, it is difficult to distinguish deposits of stage 3 from deposits of stages 4 and 5, and we have not attempted to do so in the present mapping. In some outcrops, however, tephras are present that provide a tool for geochemical correlation to known eruptions on nearby Cascade stratovolcanoes. Tephra correlations appear promising but will require more data.

As Vashon ice moved southward and grounded across the Strait of Juan de Fuca during stage 2, it dammed the northern outlet of the Puget Sound basin. Proglacial streams carried fluvial sediments southward into the Puget Lowland filling proglacial lakes and eventually the Puget Sound basin, first with silts, then sands and gravels. These sediments form the 'great lowland fill' of Booth (1994). Ice overrode these sediments, covering most of them with till, or scoured them away to deposit till directly onto pre-Vashon sediments. Subglacial channels were subsequently eroded into the fill. Proglacial lakes became impounded in these channels at different elevations above today's sea level as ice impinged on divides. The former lakebeds are presently the southernmost inlets of Puget Sound. (For a more thorough discussion of the subglacial channel network, see Booth, 1994, and Booth and Goldstein, 1994.) As these proglacial lakes spilled into lower-elevation basins and channels near the end of the Pleistocene, they deposited coarse, steeply dipping deltaic gravels along the margins of the channels and basins. Some of these deposits can be found near Shelton (to the west of this quadrangle) and Steilacoom and Fort Lewis (to the east).

Much of the drainage originating from the ice sheet flowed southward and southwestward toward the Chehalis River. Some of the drainage probably occurred as glacial-lake outburst floods when valley-blocking ice dams were breached during ice retreat. Deep troughs were carved out of the fill by subglacial fluvial erosion, and extensive and complex terraces and braided channels were formed. As the ice receded, streams near Olympia (south of this quadrangle) filled the deep troughs with sandy sediments characterized by northward-directed paleocurrent indicators. These sediments provide evidence that drainage reorganized to flow northward through the recently formed outwash plain. The thickness of these sediments (unit Qgos) varies substantially throughout the area, reaching more than 400 ft just south of the map area in a geotechnical borehole at the Port of Olympia (Washington Public Power Supply System, 1974). Unit Qgos is important because it is widespread throughout the populous South Sound area and appears to behave differently from the rest of the Vashon Drift during earthquakes (Palmer and others, 1999a,b; Bodle, 1992; King and others, 1990).

In the waning stages of the Fraser Glaciation, glacial Lake Russell covered a large area of the southern Puget Lowland and deposited a relatively thin layer (1–10 ft) of fine-grained varved sediments (unit Qgof) to an elevation of about 140 ft. These lacustrine silts (and rare clays and peats) commonly overlie Vashon till (unit Qgt).

PREVIOUS GEOLOGIC MAPPING

The glacial history and geology of south Puget Sound are summarized by Bretz (1913), who mapped the entire Puget Sound basin in reconnaissance. Molenaar and Noble (1970) and Noble and Wallace (1966) produced small-scale water resources studies. The Coastal Zone Atlas (Washington Department of Ecology, 1980a,b) provides mapping of a 2000 ft wide strip along the shoreline at a scale of 1:24,000. Walsh (1987), Walsh and others (1987), and Palmer and others (1999a) compiled and augmented previous mapping.

MAPPING METHODS

For the present map, we inspected available construction site excavations, gravel pits, and roadcuts. We surveyed the shorelines by boat and took samples and measured sections at cliff exposures. Contacts between map units are commonly not exposed and are only approximately located on this map. They are generally located by outcrop mapping, air photo and Light Detection and Ranging (LIDAR) interpretation, interpretations of water well logs from Washington Department of Ecology, and, in part, modification from Drost and others (1998). U.S. Department of Agriculture soil maps (Pringle, 1990) helped guide the location of peats and the contacts between sandy and gravelly units. Location accuracy of contacts is judged to be about 200 ft in general. In addition, the contacts between some units are gradational. We have tried to consider geotechnical significance in mapping geologic units and have attempted to show units only where they are thicker than 5 to 10 ft or mask the underlying lithology.

DESCRIPTION OF MAP UNITS

Quaternary Unconsolidated Deposits

HOLOCENE NONGLACIAL DEPOSITS

Qml **Modified land**—Soil, sediment, or other geologic material that has been locally reworked to modify the topography by excavation and (or) redistribution.

Qa **Alluvium**—Silt, sand, gravel, and peat deposited in streambeds and estuaries; includes some lacustrine and beach deposits.

Qb **Beach deposits**—Mud, sand, and gravel deposited in the intertidal zone, or residual gravel on a wave-cut platform.

Qp **Peat**—Organic and organic-matter-rich mineral sediments deposited in closed depressions; includes peat, muck, silt, and clay in and adjacent to wetlands.

Qls **Landslide deposits**—Rock, soil, and organic matter deposited by mass wasting; depending on degree of activity, location within the slide mass, type of slide, cohesiveness, and competence of materials, may be unstratified, broken, chaotic, and poorly sorted or may retain primary bedding structure; may be cut by clastic dikes or normal or reverse shear planes; surface is commonly hummocky in lower reaches of deep-seated landslides or 'stepped' with forward- or back-tilted blocks in headward areas; deep-seated slides tend to be relatively large. Slow-moving slumps (Varnes, 1978) commonly transform into slump–earth flows, can commonly be recognized by bowed or randomly tilted trees, and most commonly occur at the interface between poorly compacted, poorly cohesive, permeable sands overlying relatively impermeable silt or clay layers; shallow, more rapid debris flows commonly occur at the interface between impermeable substrate, such as till, and shallow, loose, permeable soils that are rich in organic matter. Rock topples and (or) falls that are too small to be shown at the map scale occur wherever near-vertical bluffs are present, typically because silt- or clay-rich layers such as units Qgof or Qps fail along bluffs. Unit Qls is shown only where landslides are large or obscure the underlying geology.

PLEISTOCENE GLACIAL DEPOSITS

Deposits of Continental Glaciers—Cordilleran Ice Sheet

Vashon Stade of the Fraser Glaciation

Glacial sediments described in this section consist mostly of rock types of northern provenance, most from the Canadian Coast Range. A wide variety of metamorphic and intrusive igneous rocks not indigenous to the Puget Lowland and generally southerly directed current indicators help distinguish these materials from the volcanic-lithic-rich sediments of the eastern Puget Lowland and the Crescent Basalt– and Olympic core–rich sediments of the western Puget Lowland.

Age of maximum Vashon ice advance in the map area was previously estimated to be approximately 14,000 radiocarbon yr B.P., based on apparent post-glacial deposits in the central Puget Lowland that were radiocarbon dated at about 13,600 radiocarbon yr B.P. (Porter and Swanson, 1998). However, five more-recently obtained radiocarbon dates from deposits that directly underlie Vashon till in the southern Puget Lowland indicate a maximum ice advance after about 13,400 radiocarbon years B.P. (Borden and Troost, 2001, Walsh and others, 2003b), which leaves only about 200 years for the glacial advance into and recession from the southern Puget Lowland. Most exposures mapped as Vashon till lack geochronologic data and are identified based on occurrence at or near the top of the stratigraphic section.

Qgof **Latest Vashon fine-grained sediments**—Lacustrine clayey and (or) fine sandy silt with sparse, disseminated dropstones; laminated and commonly vertically jointed; medium gray where fresh to pale yellow where dry and oxidized; distinguished by relatively darker (chocolate brown in oxidized exposures) horizontal bands about 1 in. thick that may represent annual winter depositional layers in a varve sequence; no more than about 20 apparent varves were counted in any exposure, suggesting a short life for the glacial lake(s) in which unit Qgof was deposited; present in deposits up to 10 ft thick over much of southern Puget Lowland and most commonly found at elevations below about 140 ft; mapped where it is thought to be at least about 5 ft thick or where it masks the underlying geomorphology; includes deposits of glacial Lake Russell and other lakes of the Vashon glacial recession.

Qgos **Latest Vashon recessional sand and minor silt**—Moderately well-sorted, moderately to well-rounded, fine- to medium-grained sand with minor silt; noncohesive and highly permeable; thickness inferred from wells reaches up to 100 ft within this quadrangle; deposited in and around the margins of glacial lakes; surrounds numerous steep-walled lakes and depressions (kettles), evidence that this unit was largely deposited during deglaciation when there was stagnant ice occupying much of the southern Puget Lowland.

Qgt **Vashon till**—Unsorted and highly compacted mixture of clay, silt, sand, and gravel deposited directly by glacier ice; gray where fresh and light yellowish brown where oxidized; very low permeability; most commonly matrix-supported but may be clast-supported; matrix generally feels more gritty than outwash sands when rubbed between fingers, due to being more angular than water-worked sediments; cobbles and boulders commonly faceted and (or) striated; ranges in thickness from wispy, discontinuous layers less than 1 in. thick to more than 30 ft thick; thicknesses of 2 to 10 ft are most common; till may include outwash clay, sand, silt, and gravel, or ablation till that is too thin to substantially mask the underlying, rolling till plain; erratic boulders are commonly associated with till plains but may also occur as lag deposits where the underlying deposits have been modified by meltwater; typically, weakly developed modern soil has formed on the cap of loose gravel, but the underlying till is unweathered; local textural features in the till include flow banding and apophyses extending 10 to 15 ft downward into underlying sand and gravel (or till) and that are oriented transverse to ice flow direction.

Qga
Qgas **Vashon advance outwash**—Sand and gravel and lacustrine clay, silt, and sand of northern or mixed northern and Olympic Range source, deposited during glacial advance; contains some nonglacial sediments, such as cobbles and rip-ups of silt or peat as lag along channel sides and bottoms; gray where fresh, light yellowish gray where stained; isolated exposures of lacustrine silt and clay resemble older glaciolacustrine units; sands (unit Qgas) may be tens of feet thick and are well sorted, fine-grained with lenses of coarser sand and gravel, generally permeable and porous with low cohesivity relative to overlying and underlying sediments, and subject to deep-seated landsliding.

PLEISTOCENE DEPOSITS OLDER THAN VASHON DRIFT

Qpf **Pre-Vashon glaciolacustrine deposits**—Parallel-laminated clayey and (or) fine sandy silt with rare dropstones; medium gray where fresh to light tan where dry and oxidized to olive tan where moist and oxidized; very low permeablility and porosity cause this unit to readily perch groundwater; soft-sediment deformation common; limited exposures in this quadrangle are less than 10 ft thick; organic matter rare; interpreted to have been deposited in proglacial lakes even where dropstones have not been found, because interglacial conditions in south Puget Sound do not appear to be conducive to large lakes that lack significant amounts of organic matter; may include nonglacial lake deposits.

Qps **Pre-Vashon sandy deposits**—Thin- to thick-bedded to cross-bedded sand interbedded with laminated silt and minor peat, diatomite, and gravel; commonly in upward-fining sequences; dominated by varied Cascade-source volcanic-lithic rock types; older than Vashon Drift and generally overlying or interbedded with unit Qpg; interpreted as nonglacial, but may include glacial-stage deposits, particularly from oxygen-isotope stage 4.

These sediments have previously been referred to the Kitsap Formation, and were interpreted to have been deposited during the Olympia nonglacial interval (Garling and others, 1965). Deeter (1979), however, has shown the type locality of the Kitsap Formation to include radiocarbon-infinite sediments of both glacial and nonglacial origin, and we follow his suggestion that the name be abandoned.

Further complicating the interpretation of this lithofacies is the discovery that both normal and reverse paleomagnetic layers have been found within unit Qps (Logan and others, 2003; Walsh and others, 2003a). The reversed layers are interpreted as having been deposited during the Blake reversed subchron in the Bruhnes chron. However, without other geochronologic information, we cannot rule out deposition during the Matuyama magnetic reversal.

A finite accelerator-mass-spectrometry radiocarbon date of 33,220 ±300 yr B.P. was obtained from a well near Boston Harbor from a sandy silt that is subjacent to Vashon Drift, and another sample from north of Sanderson Harbor yielded a 38,060 ±620 yr B.P. date (Table 1); all other samples in this quadrangle are radiocarbon infinite (Fairhall and others, 1966, p. 501;Yount and others, 1980).

Tree stumps in apparent growth position were observed on the east side of Squaxin Island within this unit Qps, indicating that unit there is likely interglacial.

Qpg **Pre-Vashon gravel**—Gravel and sand of northern provenance; stratigraphically underlies the Vashon Drift; most commonly exposed underneath unit Qps; gravelly portions are relatively resistant to erosion; commonly tinted orange with iron-oxide staining; moderately to poorly sorted; commonly cross bedded but may lack primary sedimentary structures; inferred to be of glacial origin because interglacial conditions do not appear conducive to streams with sufficient competency to deposit widespread gravels in most of the Puget Lowland, and because the majority of the exposures include northern-source clasts.

Contact—Approximately located

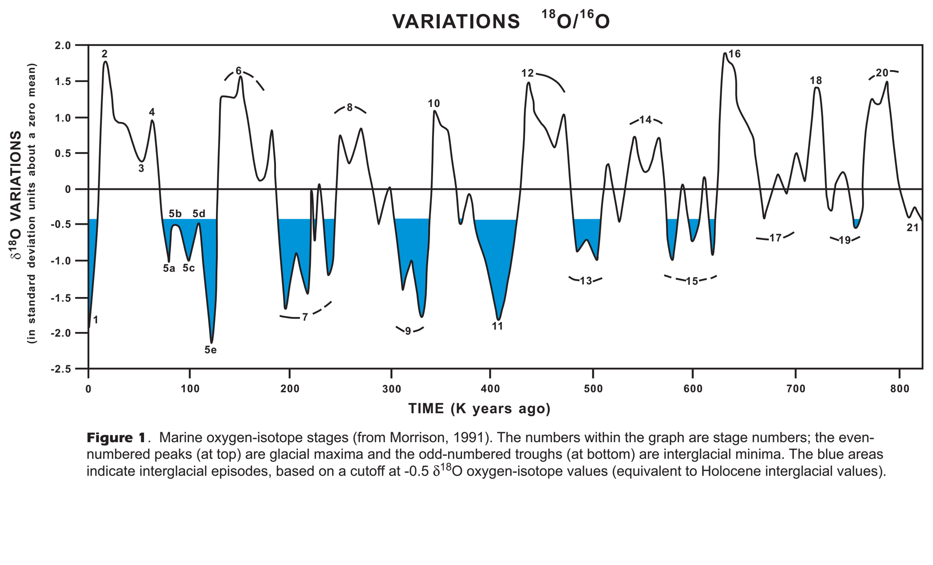


Figure 1. Marine oxygen-isotope stages (from Morrison, 1991). The numbers within the graph are stage numbers; the even-numbered peaks (at top) are glacial maxima and the odd-numbered troughs (at bottom) are interglacial minima. The blue areas indicate interglacial episodes, based on a cutoff at -0.5 $\delta^{18}O$ oxygen-isotope values (equivalent to Holocene interglacial values).

Table 1. Radiocarbon ages reported in this study. *, the location convention used herein consists of, in order, township (north), range (east or west), and section, followed by a period and then two digits indicating tenths of a mile east and north, respectively, from the southwest section corner. Additional digits are used as a unique sample identifier where multiple samples were collected from the same location. For example, 19-2W-9.98E indicates that the sample (unique identifier E) was taken from 0.9 mi east and 0.8 mi north of the southwest corner of section 9, township 19 north, range 2 west. In Donation Land Claim areas (odd-shaped sections), the letter 'X' is substituted for the distance from the southwest section corner (for example, 20-2W-20.X). **, 'Beta' indicates data from samples analyzed at Beta Analytic, Inc., for this study; 'UW' indicates data from Dorn and others (1962) and Fairhall and others (1966). ***, radiocarbon ages given as conventional radiocarbon age in uncalibrated radiocarbon years before present, where 'present' is 1950 A.D.; reported uncertainty is one standard deviation, where applicable. AMS, accelerator mass spectrometry

Location	Location detail*	Map unit	Material	Sample no.**	Conventional age (yr B.P.)***
Well near Boston Harbor	19-2W-13.25	Qps	peat	Beta 129456	33,220 ±300 (AMS date)
Eld Inlet, northeast of Sanderson Harbor	19-2W-9.98E	Qps	peat	Beta 167211	38,060 ±620
East shore of Totten Inlet	19-2W-4.28	Qps	peat	Beta 148521	>43,550
East shore of Totten Inlet	19-2W-5.62	Qps?	peat	Beta 150759	44,170 ±2,900
Northeast shore of Squaxin Island	20-2W-15.46B	Qps?	peat	Beta 156817	>44,010
West shore of Squaxin Island	20-2W-22.32A	Qps?	peat	Beta 156818	>38,950
Southern shore near east end of Hammersley Inlet	20-2W-20.X	Qps?	wood	UW-49	>45,000
Southern shore of Hammersley Inlet, east of Mill Creek	20-2W-30.19A	Qps	wood	Beta 167217	>45,280

ACKNOWLEDGMENTS

Support for identification of tephra was provided by Franklin F. Foit, Jr. (Wash. State Univ.). We have benefited greatly from discussions with Derek Booth and Kathy Troost (Univ. of Wash.) and Ray Wells and Brian Sherrod (U.S. Geological Survey). This map is supported by the National Geologic Mapping Program under Cooperative Agreement No. 00HQAG0107 with the U.S. Geological Survey. New radiocarbon ages (Table 1) were provided by Beta Analytic, Inc.

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